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Drinking frequency and locomotor activity of cows and calves as measured by triaxial accelerometers and proximity loggers

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Abstract Understanding cattle drinking behavior is essential for improving animal welfare and management strategies. This study monitored the drinking frequency and locomotor activity of pregnant cows, nursing cows, and their suckling calves via proximity loggers with integrated accelerometers. Three nursing cows, their 4-month-old calves, and 4 late-pregnancy cows were observed for seven consecutive days under farm conditions. The daily number of visits to the water trough did not differ significantly among nursing cows (3.1 ± 0.9), pregnant cows (3.4 ± 0.2), and calves (4.0 ± 0.4). All groups showed a drinking peak at 0900 h, with additional peaks at 1100 h for pregnant cows and at 1700 h for nursing cows and calves. Nursing cows were consistently more active than calves or pregnant cows and tended to have higher circadian MESOR and amplitude values. Calves had a significantly lower circadianity index, suggesting weaker and less stable daily rhythms. In conclusion, while drinking frequency was similar across physiological classes, circadian analyses revealed differences in rhythm robustness, with nursing cows exhibiting the most stable patterns and calves showing evidence of immature circadian regulation.

Keywords: cattle, water, activity, sensors

1. Introduction

Water is a fundamental nutrient for all animals, and it plays a vital role in maintaining homeostasis, thermoregulation, digestion, and metabolic functions. In cattle, adequate access to clean, fresh water is essential for survival and directly influences feed intake, milk production, growth rates, and overall health (Murphy et al., 1983; NRC, 2021). Water deprivation or suboptimal drinking behavior can lead to cascading physiological and behavioral disturbances, including dehydration, altered electrolyte balance, reduced rumination, and reduced productivity (Beede, 1993). Consequently, understanding the dynamics of drinking behavior in adult cattle and young calves is crucial for improving animal welfare and optimizing livestock management practices.

Drinking behavior encompasses several elements, including the frequency of visits to water sources, duration of drinking bouts, diurnal patterns, and social interactions around water points. A complex mix of factors, such as ambient temperature, diet composition (particularly dry matter content and salt intake) (Zoidis and Hadjigeorgiou, 2017), physiological state (e.g., lactation, growth), social hierarchy, and individual variability (Foris et al., 2023), influence those behaviors. Calves exhibit developmental changes in water intake as they transition from a milk-based diet to solid feed (Rosenberger et al., 2017), and maternal influences and social learning can influence their water-seeking behavior (Costa et al., 2016). Despite its importance, drinking behavior has been one of the least studied aspects of cattle behavior, largely because of the technical challenges associated with monitoring activity over extended periods under practical farming conditions.

Historically, the study of drinking behavior has relied on direct observation or video recording (Hedlund and Rolls, 1977), which are labor intensive, time limited, and prone to observer bias. Furthermore, those methods often fail to capture subtle behavioral variations or infrequent events, and their use in commercial settings can be impractical. In recent decades, the rise of sensor-based technologies in animal behavior research has revolutionized our ability to monitor cattle continuously, accurately, and noninvasively, e.g., computer vision (Islam et al., 2023), RFID panel readers (Williams et al., 2020), accelerometers (Williams et al., 2017), or embedded imaging systems (Tsai et al., 2020). Among the most promising technologies for behavioral monitoring are proximity loggers, which detect and record the presence of individual animals within a defined distance from a sensor-equipped object or location. Typically, those systems include a mobile tag worn by the animal (usually attached to a collar or ear tag) and a stationary node or logger that is positioned at a resource of interest, such as a water trough, feed bin, or shelter. If an animal falls within the predefined range of the sensor, an interaction event, which often includes a timestamp, signal strength, and duration of contact, is recorded (Abecia et al., 2024). Depending on the system architecture, data can be downloaded periodically or transmitted in real time.

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Proximity logging technology has been widely used to study maternal behavior in cows (Kour et al., 2021; Abecia et al., 2025) and social relationships (Meir et al., 2025) and to estimate the daily frequency of water consumption in sheep (Abecia et al., 2024). Recently, we reported significant advancements in the use of proximity logging technology for monitoring resource-specific behaviors in sheep, which demonstrated the feasibility of using collar-mounted proximity loggers and stationary data loggers placed at water troughs to automatically record the frequency and duration of water visits by individual animals (Abecia et al., 2024). However, challenges remain in distinguishing true drinking events from nondrinking visits, accounting for animals clustered around the same trough, and in correcting for signal noise caused by animal movements or environmental interference.

In this study, we used proximity loggers to monitor the drinking frequency of pregnant and lactating cows and their suckling calves over an extended period under farm conditions. The objective was to measure group-level patterns in the drinking behavior of cows (pregnant or nursing) and calves, including frequency and time-of-day preferences. In addition, because the loggers included a triaxial accelerometer, the locomotor activity (LA) of the animals was quantified.

2. Materials and Methods

2.1. Animals and sensors

Three Parda de Montaña cows (Nursing-cow group), three calves (4 months old) (Calf group), and 12 pregnant (last month of pregnancy) adult cows were housed in a 350-m^2 enclosure. Cows received feed at the same times each day, and were fed a concentrate ration at 0700 and 1400 h, and meadow hay and barley straw ad libitum. The calves had ad libitum access to concentrate feed in an area exclusively designed for them, which was not accessible to the cows. Cows and calves and four pregnant cows (Pregnant-cow group) wore a collar that held a triaxial accelerometer (46 × 33 × 15 mm; 19 g) (ActiGraph wGT3X-BT, Actigraph, USA) for 7 d. These devices also have Bluetooth (BT) technology, so they can be programmed either as transmitters of their own presence or as receivers of signals from similar devices nearby. The sensors record accelerations (activity) on the basis of the individual's amplitude (g) and frequency (Hz) of movement along three axes (x = front-to-back, y = side-to-side, and z = up–down). The activity data were downloaded as activity counts per 1 min interval via ActiLife software (ActiGraph, LLC, Pensacola, FL). Sensors were programmed to collect data at a rate of 30 Hz.

The activity counts for the three axes were used to create minute-by-minute activity data values (vector magnitude, VM), which is the magnitude of the vector that is formed from the combination of the accelerations from the three axes on each device. The VM is calculated as follows:

$$VM = \sqrt{x^2 + y^2 + z^2}$$

Data from the sensors were used to quantify the proximity of the animals to the trough and to calculate the number of drinking sessions per day. The sensors on the cows and calves were programmed to act as beacons, and two sensors were installed above the trough (Figure 1), which were programmed as receivers that recorded the serial numbers and labels of other beacons (cows and calves) nearby. The devices were programmed to scan for signals from the beacons once per minute. The beacons were programmed to send signals at 4 Hz (4 times per second).

The BT signals received by the sensors on the animals were downloaded via ActiGraph software, and to calculate the distance (m) between the animals and the drinker trough, the BT signal strength indicator (RSSI) collected by each device was transformed via the following formula:

$$\text{Distance} = (0.0012 \times \text{RSSI}^2) + (0.0936 \times \text{RSS}) + 1.9262.$$

The proximity of the animals to the drinker trough was calculated on the basis of a BT signal ≥ −57, which corresponds to a distance of ≤ 50 cm from the animal to the trough. A drink event was indicated if the signal from at least one of the receptors was −57 and lasted for > 2 min.

2.2. Statistical analysis

The average LA of cows and calves in the study period and its distribution throughout the day were calculated, and differences among groups and time of day (day vs. night) were evaluated statistically via ANOVA. Circadian rhythms in VMs were graphed by fitting the time series measurements of each animal to the cosine curve of a 24-h activity rhythm, which was obtained via the cosinor method on the Cosinor online platform (Molcan, 2019). The MESOR (midline estimating statistic of rhythm, or the average value over the entire period), amplitude (difference between the MESOR and the maximum value reached by the variable during the period), and acrophase (time of day when the variable reaches its maximum in the cycle) were calculated. The Circadianity Index (CI), which is a quantitative measure of the strength or robustness of a circadian rhythm in a biological time series, was calculated for each class. Typically, it is calculated as the proportion of the total variance in the data that is explained by the 24-hour (circadian) component via Fourier analysis. A CI near 1 indicates a highly robust and dominant circadian rhythm, and a CI near 0 suggests the absence of or a weakness in a circadian component. The proximity to the trough was calculated on the basis of the total number of BT signals per hour, and the number of drinking events per animal per day was calculated.

Figure 1 Nursing Parda de Montaña cows and calves wearing a collar that housed a triaxial accelerometer (ActiGraph wGT3X-BT; ActiGraph, FL, USA), which was used to measure locomotor activity. The sensors on the cows and calves were programmed to act as beacons, and two sensors were installed above the trough, which were programmed as receivers that recorded the serial numbers and labels of other beacons (cows and calves) nearby.

3. Results

3.1. Drinking frequency

The daily number of visits to the drinker trough did not differ significantly among the three groups (nursing cows = 3.1 ± 0.9; pregnant cows = 3.4 ± 0.2; calves = 4.0 ± 0.4).

Animals in each of the three classes presented a peak in the frequency of drinking events at 0900 h, and pregnant cows presented another peak at 1100 h. Nursing cows and calves presented another peak in frequency at 1700 h (Figure 2).

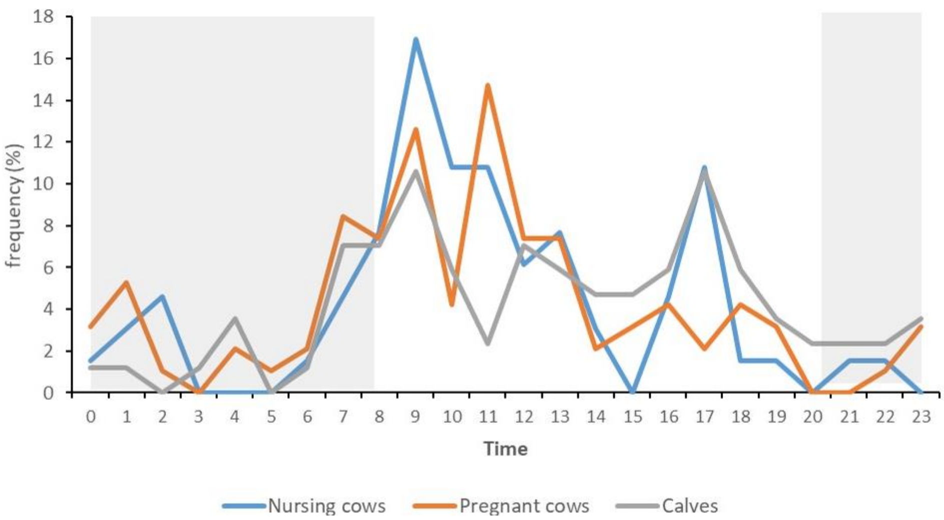

Figure 2 Mean frequency (%) of drinking events in nursing Parda de Montaña cows (n=3), their calves (n=3), and pregnant cows (n=4) as recorded by proximity sensors (gray areas indicate night).

3.2. Locomotor activity

Nursing cows presented a significantly (P<0.001) greater mean (± S.E.) LA (counts/min) (98.81 ± 0.40) than did their calves (72.91 ± 0.38) or pregnant cows (52.24 ± 0.25). Animals were significantly (P<0.001) more active during the day (154.99 ± 0.97 counts/min) than they were at night (65.09 ± 0.19 counts/min), and the differences among groups occurred during the day and at night (Table 1).

Animals in the three classes presented three peaks in activity (approximately 0800--0900 h, 1300--1400 h, and 1700--1800 h) (Figure 3), which were significantly (P<0.001) greater in nursing cows than in pregnant cows and calves (228, 124, and 142 counts/min at 0900 h; 194, 109, and 115 at 1400 h; and 161, 95, and 129 at 1800 h, respectively).

Table 1 Mean (±SEM) locomotor activity (counts/min) of nursing Parda de Montaña cows (n=3), their calves (n=3), and pregnant cows (n=4) as measured by triaxial accelerometers. Different superscripts (a, b, c) indicate significant differences among groups, P<0.05; different superscripts (x, y) indicates significant differences between day and night.

	Nursing cows	Pregnant cows	Calves
Day	217.77 ± 1.74 ^{a,x}	118.66 ± 1.36 ^{b,x}	139.43 ± 1.90 ^{c,x}
Night	87.96 ± 0.40 ^{a,y}	46.22 ± 0.24 ^{b,y}	66.89 ± 0.37 ^{c,y}

3.3. Circadian rhythms

The MESOR and amplitude of nursing cows tended to be greater (P=0.10) than those of calves or pregnant cows, but the activity of acrophases did not differ significantly (Figure 3, Table 2). Calves had a significantly (P<0.05) lower CI than did nursing or pregnant cows.

Table 2 Cosinor rhythm parameters of locomotor activity in nursing Parda de Montaña cows (n = 3), their calves (n = 3), and pregnant cows (n = 4). Values are mean (± SEM). MESOR = midline estimating statistic of rhythm (baseline activity), Amplitude = difference between MESOR and peak activity, Acrophase = time of day of peak activity, CI = circadianity index (strength of rhythm, where values closer to 1 indicate a more robust circadian pattern). Different superscripts (a, b) indicate significant differences among groups (P < 0.05).

	MESOR	Amplitude	Acrophase	CI
Nursing cows	98.00 ± 21.36^{a}	69.87 ± 11.60^{a}	12:59 ± 0.18	0.28 ± 0.03^{a}
Pregnant cows	52.97 ± 6.95^{b}	38.78 ± 5.89^{b}	12:59 ± 0.25	0.26 ± 0.03^{b}
Calves	71.98 ± 13.01^{b}	33.59 ± 7.93^{b}	12:38 ± 0.12	0.17 ± 0.04^{b}

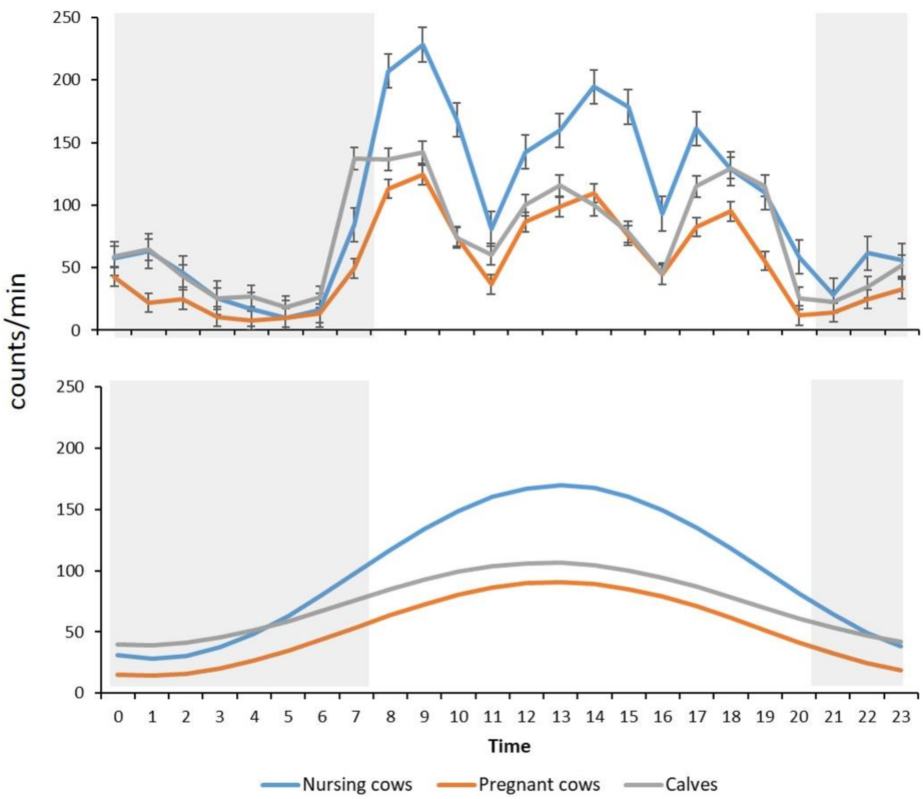

Figure 3 Locomotor activity of nursing cows (n = 3), calves (n = 3), and pregnant cows (n = 4). Upper panel: mean (± SEM) activity (counts/min) recorded by triaxial accelerometers. Lower panel: fitted cosine curves of 24-h rhythms from cosinor analysis. Gray shading indicates the nighttime period.

4. Discussion

The ability to objectively monitor drinking and other activities in cow-calf systems has important implications for animal welfare and management. Early detection of deviations from normal behavior can indicate health or resource-access issues, which can enable timely interventions. Furthermore, an understanding of the timing of drinking can inform the design and placement of water resources to minimize competition and ensure equitable access, particularly for vulnerable groups such as calves. In our study, the temporal distribution of visits to troughs revealed two consistent peaks, one in the morning (approximately 0900 h) and another in the late afternoon (1700 h). These temporal patterns might reflect behavioral synchronization within the herd, which might be influenced by feeding time, ambient temperature, or human activities. Studies have shown that cattle often develop daily drinking and feeding routines that are influenced by management and climatic conditions, e.g., increased water intake after feeding and at the warmest times of the day (Murphy et al., 1983). The drinking peak at 1100 h among pregnant cows might have been caused by individual differences in hydration needs or reduced competition at the trough at that time.

Previous studies have reported that dairy cows typically visit water sources between 7 and 12 times per day (Murphy et al., 1983; Williams et al., 2020), while beef cattle on pasture or in feedlots generally drink less frequently, around 2 to 5 times daily (Sowell et al., 1999; Islam et al., 2023). The values observed in our study (approximately 3–4 visits per day) are therefore at the lower end of the reported range. Several factors may explain this difference. First, the animals in our experiment were housed in a relatively small enclosure with constant access to water, which might have reduced exploratory or opportunistic approaches to the trough. Second, breed and physiological status could have influenced water demand, as Parda de Montaña cows are dual-purpose animals with lower milk yields than high-producing Holsteins, and pregnant cows in late gestation may reduce activity and drinking compared with lactating cows. Finally, management routines, such as synchronized feeding, likely shaped the temporal distribution of drinking events, contributing to the clear morning and afternoon peaks we detected. Importantly, very few studies have examined drinking frequency in cow–calf systems using sensor technology, so our findings provide new insights into how water use is structured when multiple physiological classes of cattle share the same resource.

The use of Bluetooth signal strength (RSSI) and signal duration thresholds means that some technical limitations might affect the measurement of drinking events. Indeed, proximity-based detection does not distinguish between actual drinking and mere presence near the trough, especially if animals loiter or engage in social interactions close to water sources (Sowell et al., 1999). Furthermore, the presence of multiple animals near the trough simultaneously might interfere with signal detection and reduce the accuracy of identifying individual drinking events (Boyland et al., 2016). The signal attenuation caused by animal posture, tag orientation, or physical barriers can influence the RSSI, which is used to detect proximity (Triguero-Ocaña et al., 2019). In another study, Abecia et al. (2024) cross-referenced proximity logger data with direct visual observations and video recordings, which indicated a strong correlation between logger-registered events and actual drinking bouts. Although not all visits to the water source involved active drinking, visit duration might serve as an indirect indicator of drinking behavior, especially if thresholds were included to exclude very short, incidental contacts. This methodological refinement will be relevant to future studies, including those involving cattle, where nondrinking proximity (e.g., standing or social clustering near water troughs) might lead to false positives without filtering.

In our study, the LA data revealed that nursing cows were significantly more active than were calves or pregnant cows throughout the 7-d period, which is consistent with our predictions on the basis of physiological and behavioral demands. Typically, lactating cows spend more time engaged in locomotor activities associated with nursing, foraging, and social interactions (von Keyserlingk et al., 2008). In addition, the presence of dependent offspring might cause nursing cows to move more frequently in response to calf vocalizations or proximity-seeking behaviors (Raussi et al., 2005). Pregnant cows, particularly in the last month of gestation, might reduce their LA as part of an energy-conserving strategy to support fetal development. A reduction in LA as gestation progresses has been documented (Davidson and Beede, 2009) and is associated with changes in posture, a reduction in foraging, and an increase in rest. In our study, the amount of LA of calves fell between those of the two adult classes, which reflected their developing motor skills and, possibly, fragmented behavior caused by their dual reliance on milk and early solid feed consumption (Costa et al., 2016).

In circadian analyses, the interpretation of parameters such as MESOR, amplitude, and CI can help to translate activity patterns into biologically meaningful information. The MESOR represents the average activity level across the 24-h cycle and can be seen as the baseline around which fluctuations occur. The amplitude reflects the strength of those fluctuations, that is, how much activity rises above (or falls below) the baseline across the day. A higher amplitude therefore indicates more pronounced daily oscillations between active and resting phases. Finally, the CI is a measure of rhythm robustness: values closer to 1 indicate a highly stable and predictable daily rhythm, while values near 0 indicate weak or irregular rhythms. In our study, nursing cows exhibited higher MESOR and amplitude values, suggesting both greater baseline activity and more pronounced day–night oscillations, whereas calves had significantly lower CI values, consistent with a less stable circadian system. This pattern aligns with previous evidence that circadian rhythms in young mammals are still maturing postnatally

(Brooks and Canal, 2013), and highlights how sensor-based metrics can provide a window into developmental differences in behavioral organization.

In our study, cosinor analysis revealed robust circadian rhythms in all groups but notable differences in rhythm strength. Nursing cows presented the highest mean activity (MESOR) and amplitude, which indicates that oscillations in activity levels were most pronounced. The CI, a quantitative measure of rhythm robustness, is significantly lower in calves than in adults, which suggests that their circadian system is less mature or less synchronized than that of adults (Duffy et al., 2015). Studies have shown that the circadian rhythm in young mammals matures postnatally; i.e., neonates and young animals typically exhibit immature or somewhat unstable biological clocks that gradually mature, which is influenced by endogenous factors and external cues (e.g., light, social interactions) (Brooks and Canal, 2013). The timing of peak activity (acrophase) did not differ significantly among the groups, which indicates that the phase of the circadian rhythm is synchronized independent of physiological state or age, possibly because of shared environmental cues and management schedules, which act as strong zeitgebers (time-givers) in group-housed livestock (Piccione et al., 2005).

5. Conclusion

In conclusion, the sensors used in this study revealed no significant differences among nursing cows, their calves, and pregnant cows in terms of the daily number of visits to the drinker trough. The amplitude of circadian rhythms in the LA differed significantly among animal classes, and nursing cows presented the most pronounced oscillations. Those cows had the most robust rhythms, which suggests a more stable circadian system. On the other hand, calves exhibited less pronounced rhythms, possibly because of the immaturity of their circadian system.

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Ethical Considerations

The study was performed at the experimental farm of the CPIFP Montearagón (Huesca, Spain; latitude 42° 06’N) following a protocol that was approved by the Ethics Committee of the University of Zaragoza on the basis of the requirements of the European Union for Scientific Procedure Establishments.

Conflicts of Interest

The authors have no conflicts of interest to disclose.

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